The Effect of Initial Conditions on the Turbulent Rayleigh-Taylor Flow

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The interface between two fluids of different densities is Rayleigh-Taylor (RT) unstable, if the light fluid accelerates the heavy. This means that small disturbances with a periodicity λ, present at the interface, grow exponentially in time. When these disturbances grow to be large, their growth rate can no longer be sustained, and their velocities saturate to a constant value, proportional to λ. Physically, the flow is comprised of *bubbles* of light fluid penetrating the heavy, while the finger-like structures of the displaced heavy fluid are referred to as *spikes*. If a glass filled with water is suddenly overturned, the air *bubble* rises along the center, while the displaced water escapes along the sides of the glass in the form of *spikes*. Such instabilities can be observed in the remnants of supernovae, effluent discharge into rivers and estuaries, and during the implosion phase of the inertial confinement fusion process, where the RT-driven mixing reduces the thermonuclear yield. Central to the control of RT-driven flows in such applications is an appreciation of the role of initial conditions on the late-time dynamics. We have studied this problem using carefully formulated high-resolution numerical simulations of the turbulent RT flow.

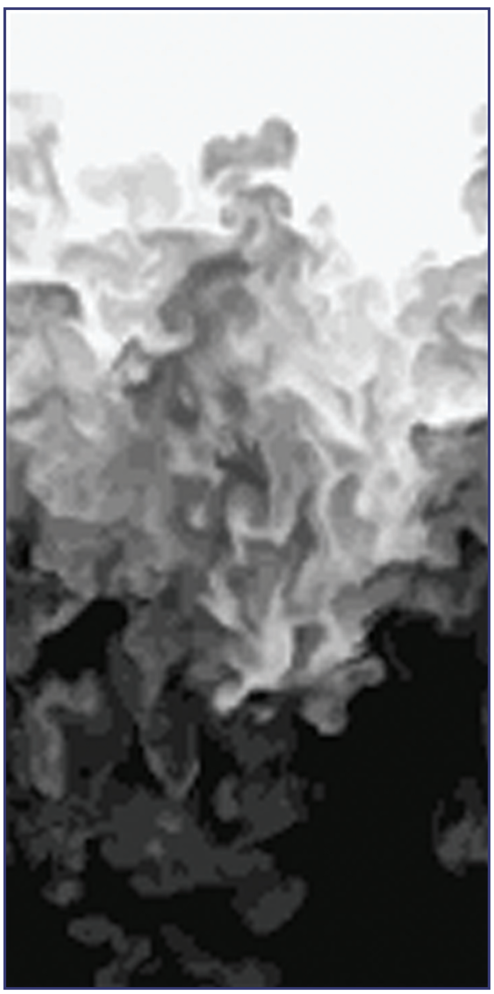

***Figure 1—* Vertical slice from 3D simulations of turbulent RT, showing leading bubbles (center of image) penetrating the heavy fluid.**

If a spectrum of modes is present at the interface, we may expect nonlinear interactions between modes, resulting in a proliferation of scales and turbulence (Fig. 1). Furthermore, this flow is self-similar because the dominant lengthscale of the flow at any instant is not externally imposed, but generated from either (a) the coupling of short-wavelength modes (also called "bubble merger"), or (b) from the growth and saturation of individual modes in the initial spectrum ("bubble competition"). A recent bubble model [1] proposes that in the first scenario, the growth rate of the flow is independent of the initial conditions, because the dominant lengthscales are formed out of the merging of two or more bubbles, which were in turn generated in the same way. Thus, the flow is primarily dominated by intrinsic scales, which can develop from a narrow-band spectrum of modes. Conversely, in the second scenario, successively longer wavelengths are "sampled" from the modes present in a broadband initial spectrum, causing the flow to remain sensitive to the initial amplitudes of modes. Our high-resolution simulations [2, 3] initialized to evolve through both these routes, validate these ideas (Fig. 2).

Furthermore, as seen in Fig. 2, the bubble merger process represents a lower-bound limit in the value of the turbulent growth rate α. We believe this explains the long-standing discrepancy in the values of α

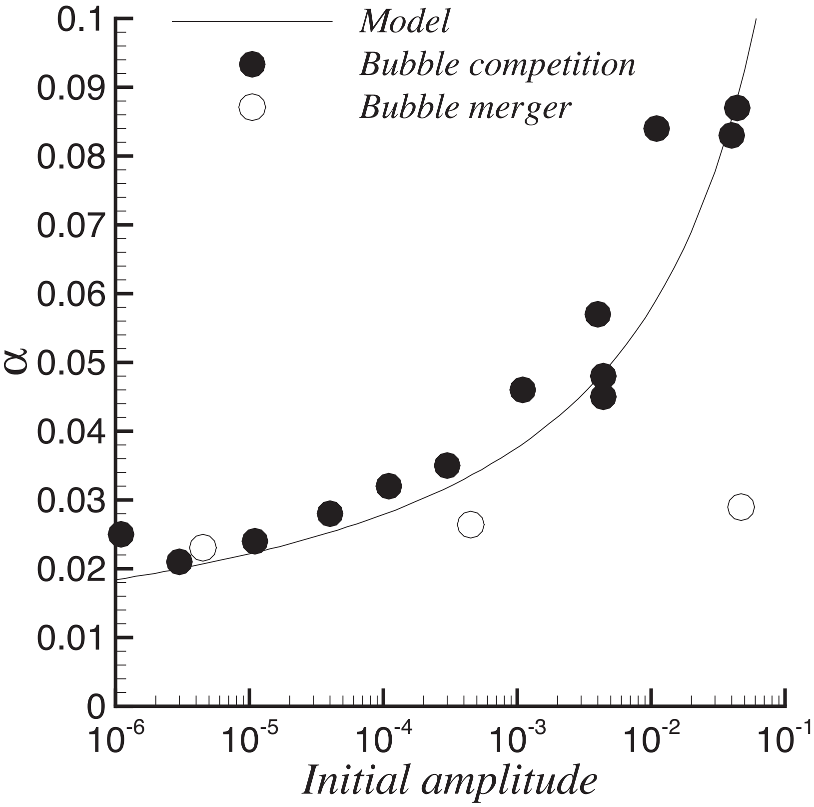

Figure 2—
Comparison of growth rates α from simulations and the bubble model of [1]. Open circles represent the bubble merger cases that are insensitive to initial amplitudes.

from experiments and numerical simulations; experiments have reported α values that are higher by 100% than the values obtained from numerical simulations. This is because numerical simulations are initialized with a narrow-band annular spectrum, and consequently evolve according to (a), while experiments have a broadband distribution of modes, imposed due to laboratory conditions, and evolve through (b). These ideas may be used in devising effective control strategies for the turbulent RT flow.

[1] Guy Dimonte, *Phys. Rev. E* **69**, 056305 (2004).
[2] Guy Dimonte et al., *Phys. Fluids* **16**, 1668 (2004).
[3] P. Ramaprabhu, Guy Dimonte, and M.J. Andrews (submitted to *J. Fluid Mech.*).

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